THE PHYSIOLOGICAL AND PERCEPTUAL RESPONSES TO CYCLING EXERCISE IN A FULLY-IMMERSIVE VIRTUAL ENVIRONMENT

By

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A Research Project submitted in partial fulfilment of the requirements of the University of Chester for the degree of M.Sc. Sports Sciences (Physiology)

30th September 2016

Word Count: 4,858

Acknowledgements

This research project has been an incredible journey. Its completion is thanks in large part to a number of special people who challenged, supported, and gave up a great amount of their time for me along the way. Firstly, I wish to express my sincere gratitude to my supervisor Dr Jamie Highton. The support I have received from Jamie for not only this research project, but during my time at university as a whole has been incredible. Jamie's feedback, guidance, availability, and quick response to my panic stricken emails has been invaluable and something I am extremely grateful for.

My sincere thanks also goes to Dr Craig Twist. Despite not being my supervisor, Craig has showed continuous interest throughout and was always willing to provide additional support and guidance whenever needed. I would also like to take this final opportunity to thank Craig for inspiring my interest in exercise physiology in the first place. I consider myself extremely fortunate to have been taught by someone with such a genuine passion and excitement for their subject.

I would also like to thank Dr Serban Pop and PhD student Tom Day. Not only did they design and develop the virtual environments for us to use, but also spent what now feels like an endless amount of hours in the laboratory with us testing. Without Serban's passion and drive for this project I am sure we wouldn't have made it over half of the many hurdles that we faced.

Perhaps the greatest thanks must go to my good friend Gerard Nowlan. Our friendship and rivalry throughout our time at Chester is what has pushed me to achieve everything that I have done so far. Working with Gerard on this project often made it feel like it wasn't work at all and I sincerely hope that at some point we will work together again in the future.

Last but not least, I would like to thank my family and my girlfriend. It has been a tough year since losing Mum but by pulling together and helping each other out we have all gone on to achieve everything she would have wanted us to and more.

Abstract

With recent advancements in technology, fully-immersive virtual reality (VR) is now fast emerging as the latest piece of equipment that may revolutionise the way in which athletes are able to train. However, as of yet, few have examined the perceptual and physiological responses to exercising in VR and the subsequent impact it may have on performance. Using a repeated measures randomised crossover design, thirteen recreationally active participants (age = 24.9 ± 4.6 y; body mass = 78.7 ± 6.3 kg; stature = 178.6 ± 3.7 cm; VO_{2max} = 55.1 ± 7.1 ml·kg^{-1}·min^{-1}, P-VO_2 =344.7 ± 49.7) completed a time to exhaustion test (TTE) at 80% of P-VO_2 under a control (CON) and virtual reality (VR) condition, with a minimum of 48h between trials. TTE (ES = 0.78; ±0.37), enjoyment (ES = 0.85; ±0.49) and positive affect (ES = 0.78; ±0.65) were all greater in the VR condition compared to CON. Rating of perceived exertion (RPE) increased similarly over time in both conditions with the exception of minute 2, whereby RPE was lower in the VR condition (ES = 0.88; ±0.52). There were no changes in VO_2 peak, b[La] and negative affect between conditions. These findings provide evidence to suggest that during the early stages of high intensity activity fully-immersive VR has the potential to reduce RPE. Further to this, VR also appears to increase the enjoyment of exercise at a high intensity and therefore increase the motivation to continue exercising. Future research should continue to explore this rapidly developing technology.

Declaration

No portion of the work referred to in this Research Project has been submitted in support of an application for another degree or qualification of this, or any other University or institute of learning.

The project was supervised by a member of academic staff, but is essentially the work of the author.

Signed:

Date: 29th September 2016

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Chapter 1

Introduction

1. Introduction

In an attempt to maintain a competitive edge over their rivals, athletes and sport scientists are continually searching for new and novel ways to optimise training and performance. With recent advancements in technology, virtual reality (VR) is now fast emerging as the latest piece of equipment that may revolutionise the way in which athletes are able to train.

The recent development of commercially available VR headsets has meant VR technology is already starting to make its way into elite level sport. For example, American triathlete Gwen Jorgenson recently used VR to prepare for the cycling section of the women's triathlon at the Rio Olympic Games (Popular Science, 2016). By capturing the whole course on a series of 360 degree cameras, her team were able to convert this into VR allowing her to experience the course through a headset. This allowed her to view the course multiple times meaning she could study every aspect in fine detail and then visually rehearse the strategy that she planned to use during the race. Jorgensen went on to win a Gold medal at the games.

However, whilst VR appears to be a powerful visualisation tool for athletes who wish to familiarise themselves with an upcoming event, there may be far more beneficial ways in which this form of technology can be utilised. For example, there now exists a substantial amount of evidence to suggest that the use of visual and auditory stimuli during exercise can elicit a number of positive psychological and psychophysiological responses, which in turn, can lead to an enhancement in performance (Barwood, Weston, Thelwell & Page, 2009; Cook & Crewther, 2012; Chow, 2012; Isik, Ersoz, Pazan & Ocak, 2015; Hutchinson, Karageorghis, & Jones, 2014; Karageorghis & Priest, 2012; Loizou & Karageorghis, 2015). These psychological responses have included enhanced affect, reduced ratings of perceived exertion, as well as improvements in motivation, behaviour, and cognition. Collectively the research suggests that these responses can be attributed to the dissociative effects of music and video, in that attention is diverted from the uncomfortable internal sensations associated with exercise towards the external distracting stimuli. The psychophysiological effects (which refer to the physiological correlates of the psychological effects) have included changes in heart rate (HR), oxygen consumption (VO_2), blood pressure, and breathing frequency, as well as changes in hormonal concentrations such as free testosterone and cortisol concentration. The psychophysiological responses brought on by the additional sensory stimuli are said to occur primarily as the result of stimulation of areas of the brain that govern arousal (Bigliassi, Karageorghis, Wright, Orgs, & Nowicky, 2016). However, further to this there is also evidence to suggest that when various forms of sensory stimuli are used in combination, there appears to be an additive effect (Loizou, Karageorghis & Bishop, 2014). Therefore, as VR can provide heightened sensory stimulation, simultaneously across multiple human senses, it stands to reason that by combining VR with exercise this may be a further way in which the training stimulus of an athlete can potentially be enhanced.

1.2. Virtual Reality

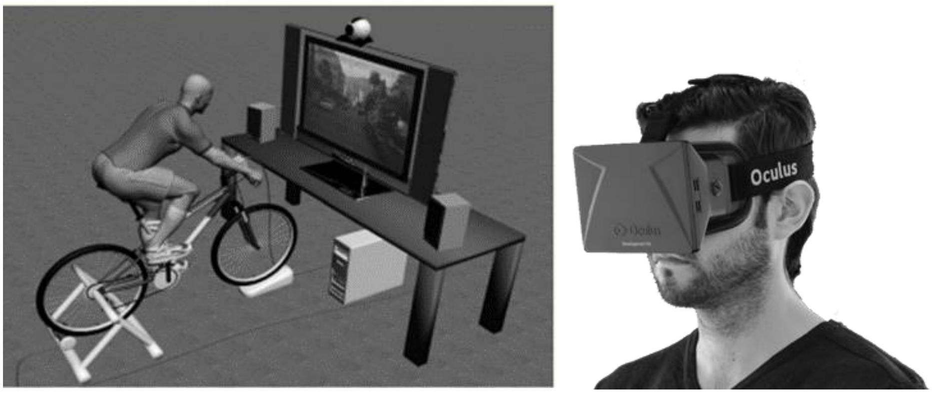
The use of VR reality within an exercise setting has been previously explored by a small number of researchers with generally positive findings (Hoffman, Filippeschib, Ruffaldib & Bardy, 2014; Nunes, Nedel & Roesler, 2014; Mestre, Dagonneau & Mercier, 2011 Mestre, Ewald, & Maino, 2011; Murray, Neumann, Moffitt & Thomas, 2015; Plante, Aldridge, Bogden & Hanelin, 2003). However, as fully-immersive VR headsets have only recently become available, the research that has been conducted thus far has used a far simpler form of VR, known as "Desktop VR".

1.2.1 Desktop Virtual Reality

In this format, VR is presented to the user in a video-game-like fashion via a computer screen positioned in front of them (Figure 1.1. a). This form of VR is typically experienced from a first person view or by looking at an avatar. The actions of the avatar in the virtual environment respond in real time to the actions of the user in the real world. As a result of combining this type of VR with traditional exercise tasks (stationary cycling, treadmill running, ergometer rowing), greater levels of physical exertion, as measured by greater RPM (Plante et al.,2003), heart rate (HR), perceived exertion (Mestre et al., 2011) time trial performance and distance covered (Hoffman et al., 2014; Murray et al., 2015) have been observed. Additionally, several studies have also reported a number of psychological parameters to be enhanced such as motivation, enjoyment, and mood (Plante et al., 2003; Mestre et al.,2011). In a similar way to the researchers who have examined the use of music and video, the authors of the aforementioned VR studies have suggested that the positive effects experienced whilst using desktop VR have been the results of its dissociative effects.

1.2.2 Fully-immersive Virtual Reality

Fully-immersive VR involves the use of a head-mounted display in the form of goggles or a helmet (Figure 1.1b). Head-mounted display units use two different screens (one for each eye) to display two different views, slightly offset from each other, that are rendered. A tracking sensor that communicates with a computer system is used to track the users head movement to assess where the user is looking. The computer then reacts to quickly display a visual image from the appropriate vantage point. This allows the person using the headset to experience the virtual environment in a manner similar to that of the real world (Sherman & Craig, 2002).



a) **b)**

Figure 1.1 a) An example of how a bike would be used with desktop VR. **b)** A virtual reality headset as used in fully-immersive VR.

1.2.3 Presence and dissociation

The distinguishing feature of fully-immersive VR compared to desktop VR is the greater feeling user's experience of presence (Slater & Wilbur, 1997). The greater the feeling of presence within an environment the higher degree to which the user perceives the virtual environment as the reality that surrounds them, rather than just images on screens (Tuzun & Ozdinc, 2016). The concept of presence can be divided into detachment from, and immersion into, the virtual environment. Presence is reduced in cases of detachment and increased in cases of immersion (Thie & Wjik, 1998). The perception of presence can be influenced by sensory factors, control factors, distraction factors and realism factors. The closer a user's interaction with the virtual environment and their control over events replicates the real world, the greater level to which distractors are minimised and immersion is increased (Tuzun & Ozdinc, 2016). Presence is generally considered a positive outcome of virtual environments, leading to greater engagement and more intense feeling of enjoyment (Ijsselsteijn, De Kort, Bonants, Jager & Westerink, 2004).

Whilst the use of desktop VR has proven itself a potentially useful tool within an exercise environment, a virtual world experienced through a fully-immersive headset offers an experience that provides far greater sensory stimulation. As previous research has highlighted the dissociative effects of additional sensory stimuli as the key mechanism for improvements in performance, use of a fully-immersive headset could see performance improved beyond that of previously explored audio and visual devices.

1.3. Rationale and Hypothesis

With the rapid and most recent developments of commercially available headsets, including those that can be used with mobile phones, fully-immersive VR will soon be accessible to large numbers of the population. With numerous exercise environments already being produced and available online, research that examines their use certainly appears warranted. To the authors knowledge no research has currently examined the use of a fully-immersive VR headset within an exercise setting. Whilst past research using desktop VR has provided a useful foundation upon which further research can be built, there is still much to be learnt about the potential of this fast emerging technology. Few researchers have fully considered the perceptual and physiological responses to exercising in VR and the potential they may have for improving performance. With the exception of HR which was measured by Mestre et al (2011) and Plante et al., (2003) there is currently no research that has examined the physiological responses to exercise in VR. Whilst a number of studies have measured various psychological responses, it is important to take these in combination with the physiological responses if we are to gain a true understanding of the mechanisms behind any changes in performance.

Through the use of fully-immersive VR there exists the potential to create and manipulate an endless amount of virtual environments, therefore allowing coaches and/or athletes' deterministic control over the situations athletes are exercising in. Through manipulation of the sensory stimuli, fully-immersive VR may allow athletes to train in a whole range of exciting and challenging environments. This includes the opportunity to create virtual worlds that, in terms of sensory input, replicate far closer the experiences an athlete may feel in competition. This includes not only computer generated environments but also real life environments that have been captured by 360 degree cameras and converted into VR. This may not only serve as a great aid for training, but could also provide the world of sport science a far greater environment from which to attempt to measure the physiological responses to exercise seen in competition. This may have large implications for the validity of a number of exercise tests regularly carried out in laboratories

The hypotheses for the current study were that in the fully-immersive VR condition a) exercise performance will be enhanced, meaning time to exhaustion will be increased. b) There will be a greater physiological response to exercise (i.e. increased HR, blood lactate concentration (b[La]) and VO_2), c) Enjoyment and motivation whilst performing the exercise in VR will be enhanced.

Chapter 2

Methods

2.1 Participants

Thirteen eligible subjects agreed to take part in this study. Participant characteristics are presented in table 2.1. Upon recruitment participants were provided with both an oral and written explanation of the study protocol (appendix A) and given the opportunity to make any further enquires. Participants then signed an informed consent form describing the study protocol (appendix B), which was approved by the Ethics Committee of the University of Chester (appendix C). Prior to testing participants were health screened and completed a pre-test health questionnaire (appendix D). In order to be eligible participants were required to be recreationally active, aged between 18 and 45, free of any known disease, and not taking any medication with the exception of contraceptives.

Table 2.1. Participant characteristics

n	Age (y)	Body Mass (kg)	Stature (cm)	VO_{2MAX} (ml/kg/min)	P-VO_2
13	24.9 ± 4.6	78.7 ±6.3	178.6 ±3.7	55.1 ± 7.1	344.7 ± 49.7

2.2 Study design

This study employed a repeated measures, randomised, cross over design in which participants visited the laboratory on three separate occasions (see Figure 2.1). For the first visit participants completed a ramp test to exhaustion and familiarisation with the VR headset. For the second and third visits participants completed a time to exhaustion test (TTE) in which they were required to cycle to exhaustion at a steady workload corresponding to 80% of peak power output achieved during their ramp test.

For one of the TTE tests participants completed the exercise protocol under normal laboratory conditions (CON). In the other trial participants completed the same protocol but whilst wearing a virtual reality headset (VR) (for detailed description of each testing condition see procedures). The order of trials was randomly allocated according to balanced permutations generated by a web-based computer program (Research Randomizer, Version 4.0).

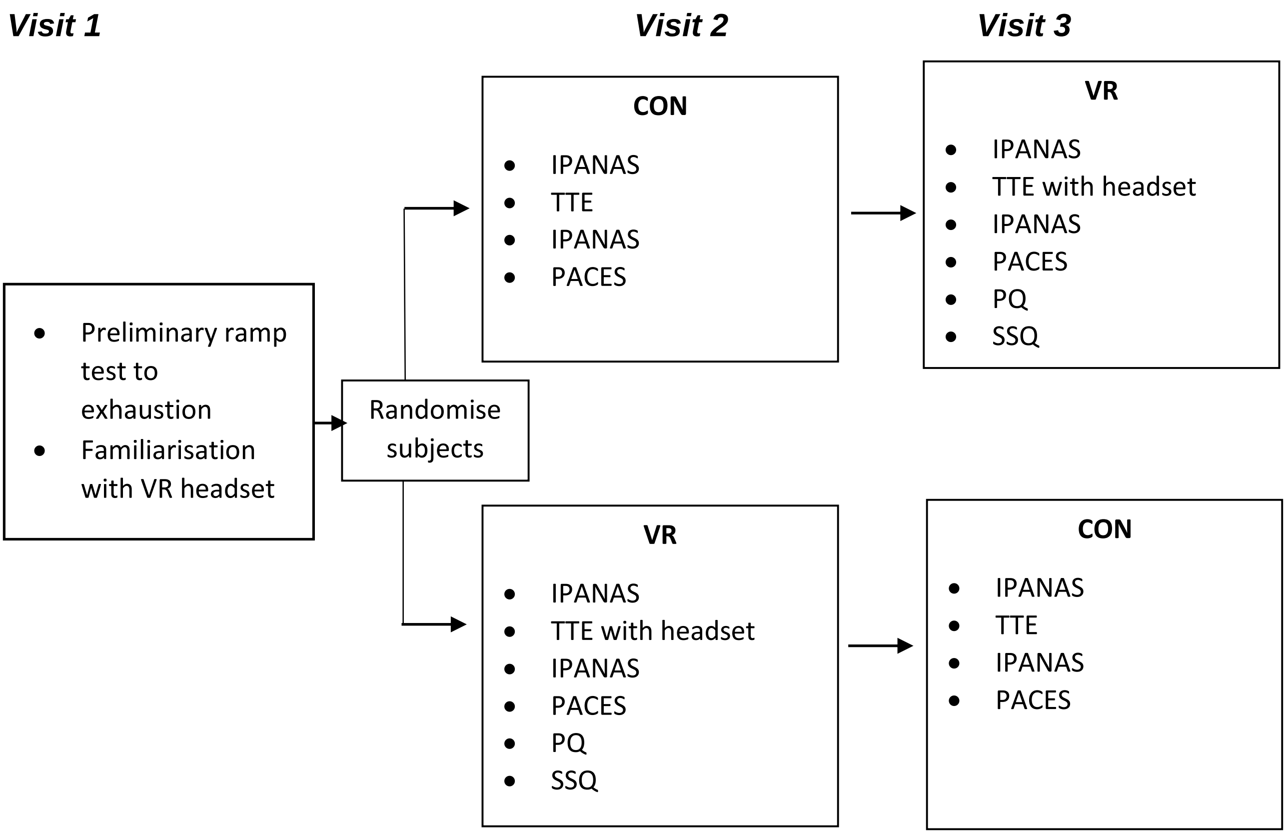


Figure 2.1 Schematic of Study Design. (TTE = time to exhaustion, IPANAS = International Positive And Negative Affect Scale, PACES = Physical Activity Enjoyment Scale, SSQ = Simulator sickness Questionnaire, PQ = Presence Questionnaire.

Each participant completed the testing over a maximum of 2 weeks, with a minimum of 48h recovery between each visit. All trials were conducted in the same laboratory at the same time of day to minimise circadian Variation. Environmental conditions in the laboratory were kept between 18-22℃ for temperature and 45-60% for humidity. Subjects were required to complete a food and exercise diary 24 hours prior to their first trial, during which they were instructed to refrain from any strenuous exercise and alcohol and caffeine consumption. Participants were then told to replicate their eating and activity habits in the 24 hours prior to their subsequent visit. Finally, participants were blinded from all performance data until they had completed the study.

2.3 Procedures

2.3.1 Preliminary Ramp Test to Exhaustion

To establish participant's maximal oxygen uptake (VO_{2MAX}) and peak power output a fast ramp exercise test was performed until exhaustion, using an electromagnetically braked cycle ergometer (Lode, Excalibur (Sport), Groningen, Netherland). The cycle ergometer was set in hyperbolic mode allowing for the power output to be set independent of pedal frequency. Male and female participants started the test at 100 W and 50 W respectively, with the test then progressing at a rate of 1 W every 3 s. Participants were instructed to cycle at a self-selected pedal frequency between 60-100 RPM, and to continue until they reached exhaustion (operationally defined as a pedal frequency of less than 60 RPM for more than 5 s despite verbal encouragement). When participants felt they had less than 30 s remaining, they were required to indicate their rating of perceived exertion (RPE) using a 15-point scale (Borg, 1998). Heart rate was measured throughout using a chest strap heart rate monitor (Polar Electro, Oy, Finland). Oxygen uptake was measured breath by breath via an online portable gas analyser (Oxycon Pro, Viasys Healthcare, Hoechberg, Germany) which averaged data over 30s periods. Upon completion of the test blood lactate (b[La]) was measured via a fingertip capillary blood sample and analysed using a portable lactate analyser (Lactate Pro, Arkay, Kyoto, Japan). All test data was then analysed according to the British Association of Sports and Exercise Science (BASES) criteria for VO_{2MAX} testing (Bird & Davidson, 1997). In instances whereby criteria for VO_{2MAX} was not met, VO_{2PEAK} which has been shown to be a valid index of VO_{2MAX} (Cooke, 2009) was used instead.

2.3.2 Experimental Trials

Prior to exercise in each of the TTE tests, participants were required to complete a psychological questionnaire related to their affective state (I-PANAS-SF). Upon cessation of the TTE test participants were required to complete the same questionnaire and a questionnaire relating to their enjoyment of the exercise (PACES). After completing the VR trial, participants were also required to complete a presence questionnaire and a simulator sickness questionnaire (detailed explanations of each questionnaire can be found in appendix E, F, G and H).

2.3.3 Time to Exhaustion test

After a 3 minute warm-up at 40% of their peak power output participants cycled at a work rate corresponding to 80% of their peak power output until exhaustion (exhaustion defined by the same definition as the VO_{2MAX} test). The cycle ergometer was again set in hyperbolic mode and participants were instructed to cycle at a freely chosen pedal frequency. Time to exhaustion was measured from the start of the exercise (not including the warm-up) until the participants RPM dropped below 60 for more than 5 seconds despite verbal encouragement or indicated they wished to stop due to volitional exhaustion. Participants HR and VO_2 were measured throughout. Upon cessation of exercise b[La] assessed from a fingertip capillary blood sample. Every 2 minutes during the exercise participants were required to indicate their RPE (Borg, 1998). In the control condition RPE was measured using the same method as detailed in the ramp test section. In the VR condition the scale used to measure RPE appeared on the virtual road in front of the participant so as not to disturb “presence” within the virtual environment. This form of high intensity constant power cycling test has been shown previously to be sensitive to changes in endurance performance (Amman & Dempsey, 2008).

2.3.3.1 Control Trial

For the control trial participants completed the TTE under normal laboratory testing conditions. All background noise and movement was kept to a minimum to ensure the exercise was performed without the addition of any further stimuli that may have had an impact on performance. Participants were unable to view their RPM, distance covered or duration of the exercise.

2.3.3.2 Virtual Reality Trial

Participants completed the TTE test wearing a virtual reality headset (Oculus Rift DK2, Oculus VR, California, United States). The headset was connected to a computer running Microsoft Windows which supported the Oculus VR software. A positional tracking system called ‘Constellation’ was used to optically track the position of the users head via external infrared sensors. The virtual environment consisted of a straight road situated within a barren landscape with a bright blue sky as if a sunny day. The accompanying audio was received via noise cancelling headphones (Beats Studio, Beats Electronics LLC, California, USA), and consisted of an audio recording that replicated the sound of a bike on the road when cycling outside. The user moved through the environment at a speed corresponding to cycling at 20kph. Participants were again unable to view their RPM, distance covered or duration of the exercise.

2.4 Statistical Analysis

All data are presented as means ± standard deviation (SD). Effect sizes (ES) and magnitude based inferences were calculated for all variables between CON and VR trials using the approach suggested by Batterham and Hopkins (2006). The thresholds for the magnitude of the observed change for each variable was determined as the between participants SD in that variable x 0.2, 0.6 and 1.2 representative of a small, moderate and large effect, respectively (Hopkins, Marshall, Batterham & Hanin, 2009). Threshold probabilities for a meaningful effect based on the 90% confidence limits were <0.5% to 25% unlikely, 25% to 75% possibly, 75% to 95% likely, 95% to 99.5% very likely, and >99.5% most likely. All calculations were made using a predesigned spreadsheet (Hopkins, 2006). For HR and RPE data an isotime of 6 min was chosen to include all subjects in the analyses. In order to examine whether feelings of presence were related to changes in TTE a Pearson's correlation was performed using SPSS statistics software (SPSS, INC, IBM, Chicago, USA). The strength of the correlation was reported using the guide by Evans (1996) whereby .00-.19 is very weak, .20-.39 is weak, .40-.59 is moderate, .60-.79 is strong, and .80-1.0 is very strong.

Chapter 3

Results

3.1 Effect of Virtual Reality on Time to Exhaustion

Time to exhaustion is displayed in figure 3.1. There was a *very likely* moderate increase in time to exhaustion in VR compared to CON (598.8 ± 133.3 vs 498.8 ± 119.5 s, ES = 0.78; ±0.37). Individual time to exhaustion was improved in the VR condition for 10 of the 13 subjects.

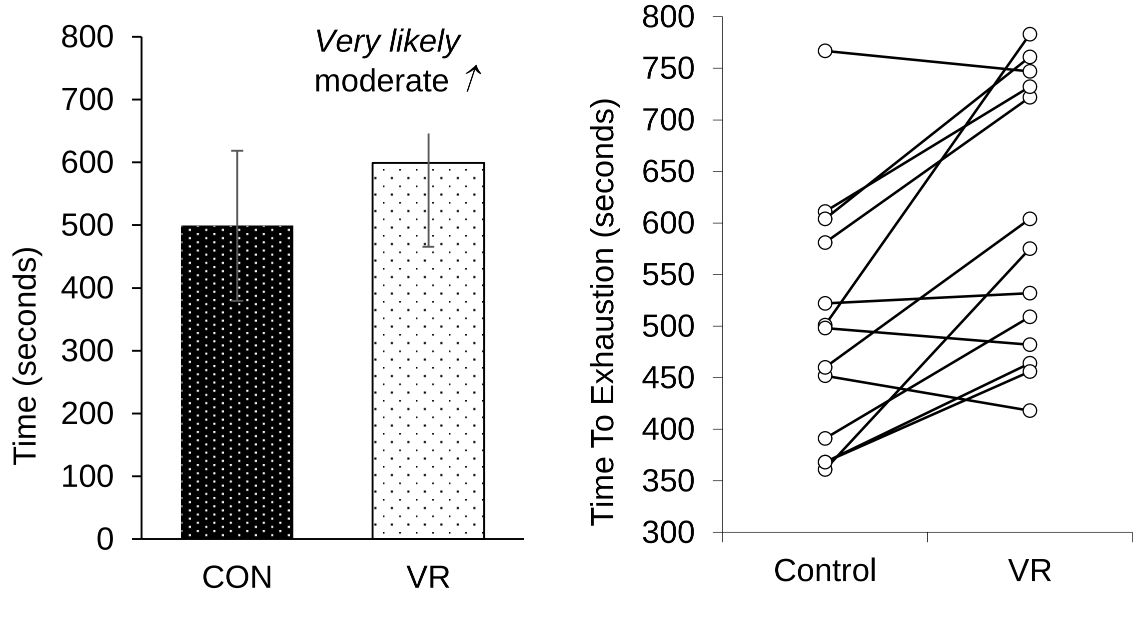


Figure 3.1. a) Average and **b)** individual **t**ime to exhaustion in CON and VR conditions. Data presented as mean ± SD with qualitative descriptor between conditions.

3.2 Effect of Virtual Reality on Physiological Responses to Exercise

The blood lactate, heart rate and VO2 responses to the CON and VR trials are displayed in figure 3.2. The difference in blood lactate concentration pre exercise between conditions was *unclear* (CON 1.35 ± 0.38 vs VR 1.22 ± 0.2 mmol/l, ES = 0.32; ±0.54). Similarly, blood lactate results post exercise were also *unclear* suggesting a similar response in both CON and VR conditions (12.35 ± 3.5 vs 11.79 ± 2.75 mmol/l, ES = 0.15; ±0.49).

Peak oxygen consumption was also similar between CON and VR conditions (4283.38 ± 650.71 vs 4333.62 ± 465.461, ES = 0.07; ±0.24, *unclear*).

Differences in heart rate response during the CON and VR conditions were *unclear* at rest (ES = 0.01; ±0.38) and at minute 4 (ES = 0.16; ±0.38). There were *possibly* trivial differences between conditions at minute 6 (ES = 0.15; ±0.32) and at exhaustion (ES = 0.19; ±0.28). There was however *possibly* a small increase in heart rate in the CON condition compared to VR at minute 2 (163.1 ± 11.43 vs 159.01 ± 15.51 bpm^{-1}, ES = 0.33; ±0.38).

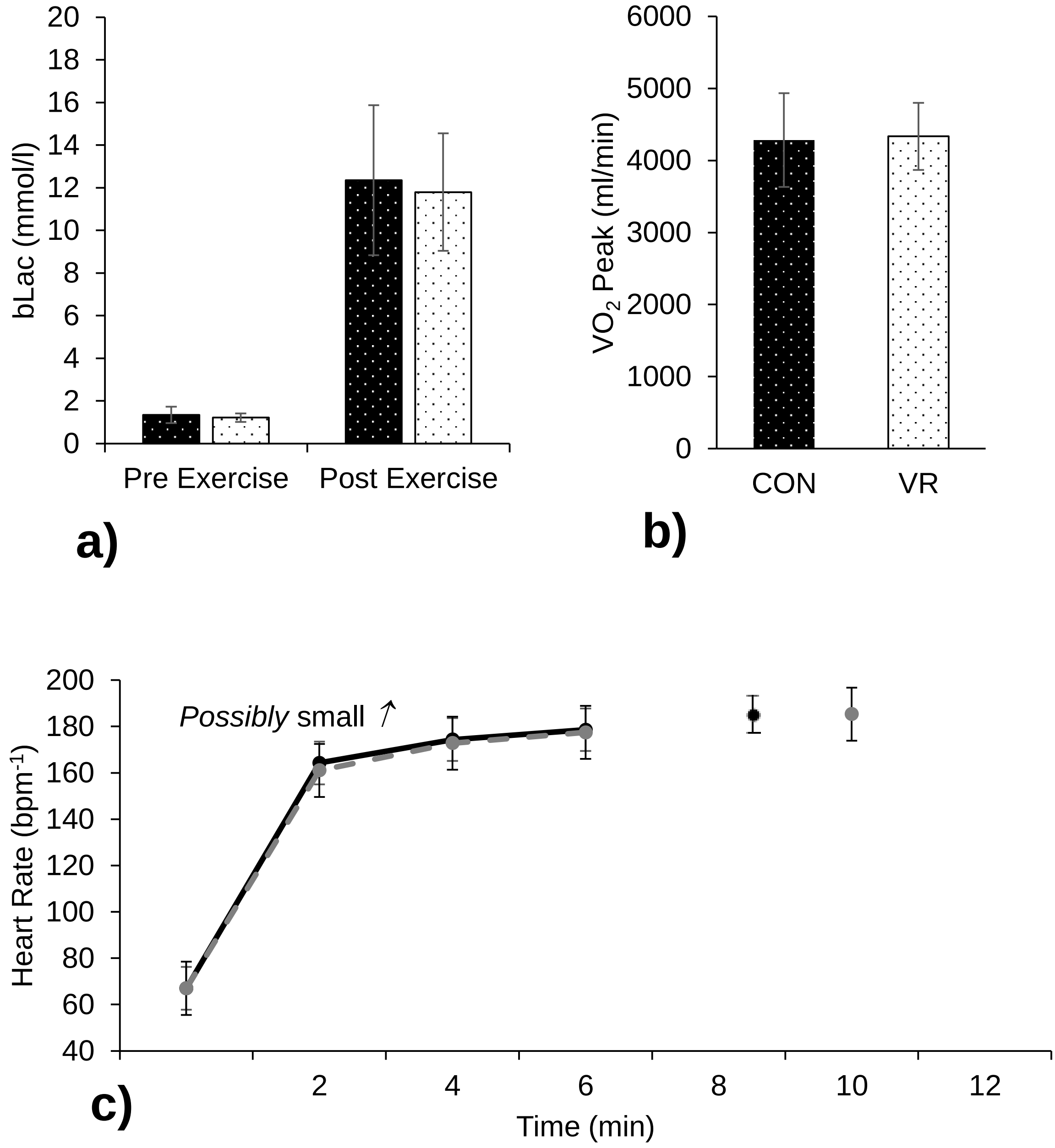


Figure 3.2. Physiological responses to exercise for CON ■ and VR □ conditions a) blood lactate b) oxygen consumption c) heart rate at isotime. Data presented as means ± SD. *Minute 0* represents resting heart rate.

3.3 Effect of Virtual Reality on Perceptual Responses to Exercise

Rating of perceived exertion at isotime is displayed in figure 3.5. There were no differences in RPE between CON and VR conditions at rest or at exhaustion. At minute 4 (16.2 ± 1.3 vs 16.5 ± 0.8; ES = 0.46; ±0.62) and minute 6 (18.2 ± 1.1 vs 18.7 ± 0.9; ES = 0.46; ±0.43) of isotime RPE was *likely* a small decrease in VR compared to CON. At minute 2 RPE there was a *very likely* moderate decrease in the VR condition (13.1 ± 1.3 vs 14.3 ± 1.3; ES = 0.88; ±0.52).

There was a *likely* moderate increase in positive affect from pre to post exercise in the CON condition (14.69 ± 3.59 vs 17.69 ± 4.19; ES = 1.39; ±0.76). However, in comparison there was a very likely large increase in positive affect pre to post exercise in the VR condition (14.23 ± 4.25 vs 20.54 ± 3.84; ES = 0.78; ±0.65) (Figure 3.4). There were no differences in negative affect at either time points in both conditions. There was a very likely moderate increase in enjoyment of exercise in the VR condition compared to CON (29.4 ± 6.8 vs 16.2 ± 14.5; ES = 0.85; ±0.49) (Figure 3.3).

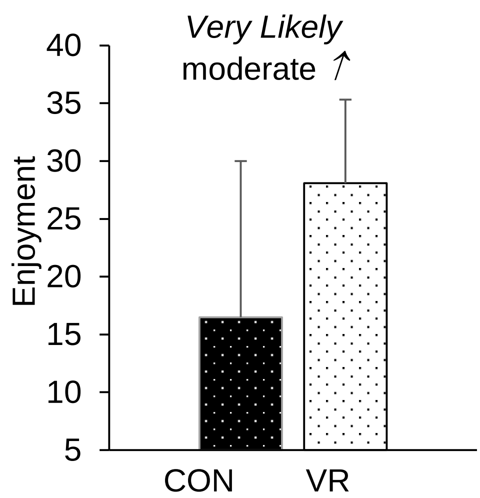


Figure 3.3. Enjoyment of exercise in CON ■ and VR □ conditions. Data presented as mean ± SD with qualitative descriptor between conditions.

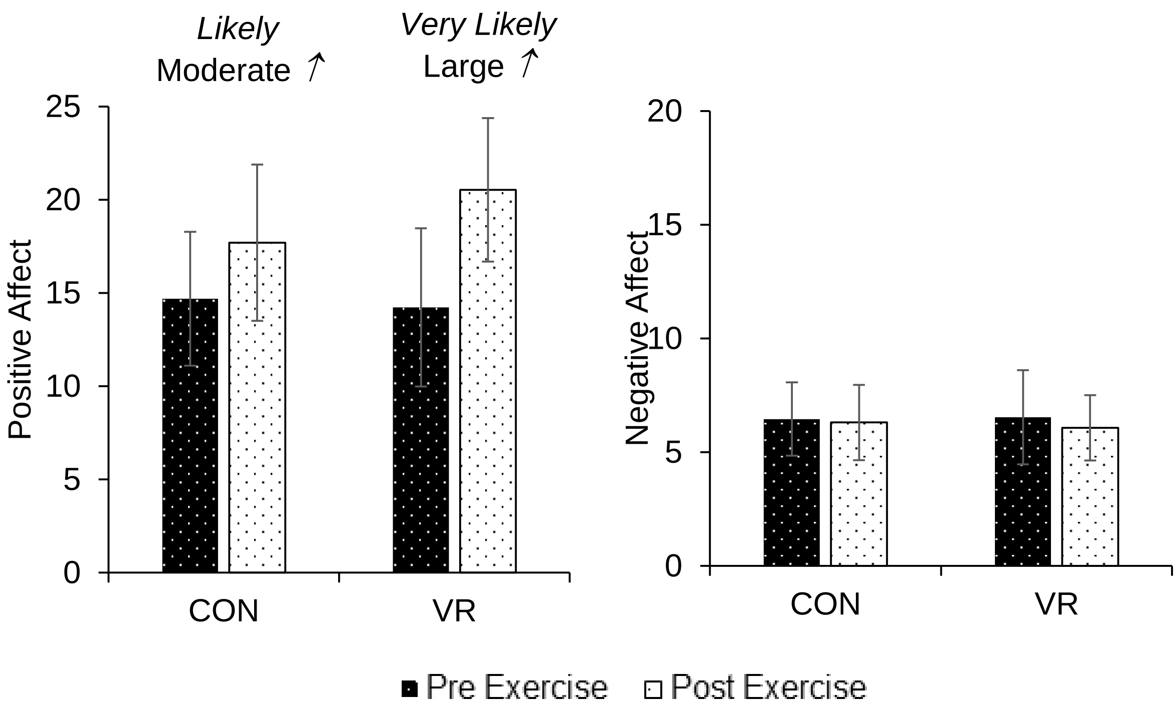


Figure 3.4. Measures of positive and negative affect pre and post exercise in CON and VR conditions. Data presented as mean ± SD with qualitative descriptor between conditions.

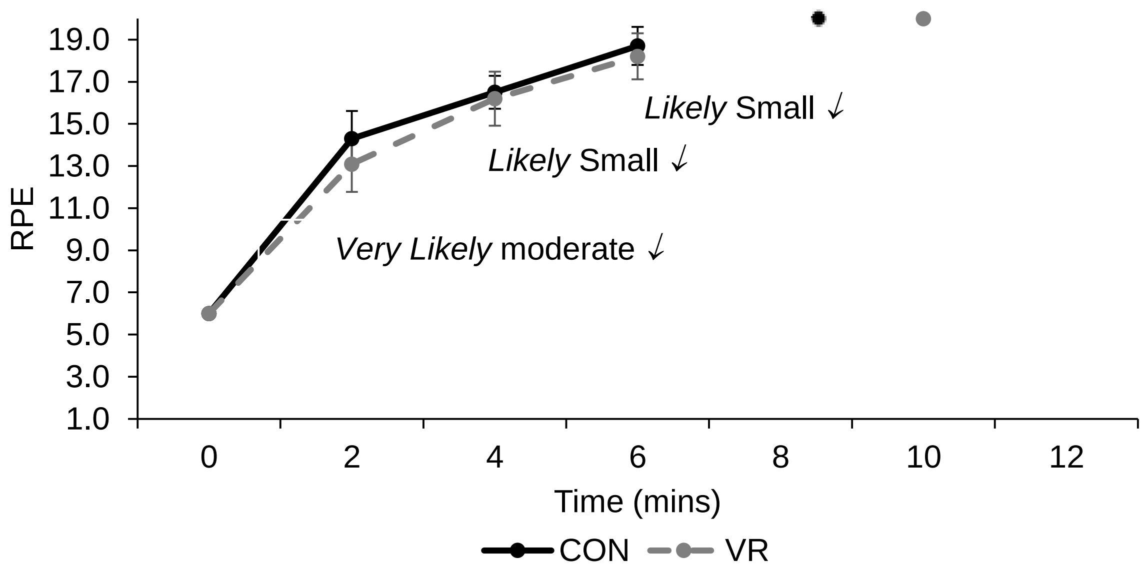


Figure 3.5. Rating of perceived exertion at isotime. Data presented as mean ± SD with qualitative descriptor between conditions. *Minute 0* represents rating of perceived exertion at rest.

3.4 Simulator Sickness and Presence

Analysis of the SSQ revealed 11 of the 13 subjects to report at least one symptom of simulator sickness. Of the three categories of symptoms that make up simulator sickness, feelings associated with nausea were experienced the most followed by oculomotor and disorientation symptoms respectively (Table 3.1). Despite, reporting these symptoms, each subject was able to carry reporting that the symptom was not great enough to make them stop or to interfere with their performance of the exercise.

Table 3.1. Simulator sickness score for each component

Nausea	Oculomotor	Disorientation
32.29 ± 21.87	25.36 ± 19.27	24.68 ± 29.06

A Pearson's correlation was computed to assess the relationship between presence within the VR environment and the change in TTE performance in VR compared to CON. There was a *very weak* positive correlation between the two variables (r = .157, n = 13, P = 0.608) (Figure 3.6).

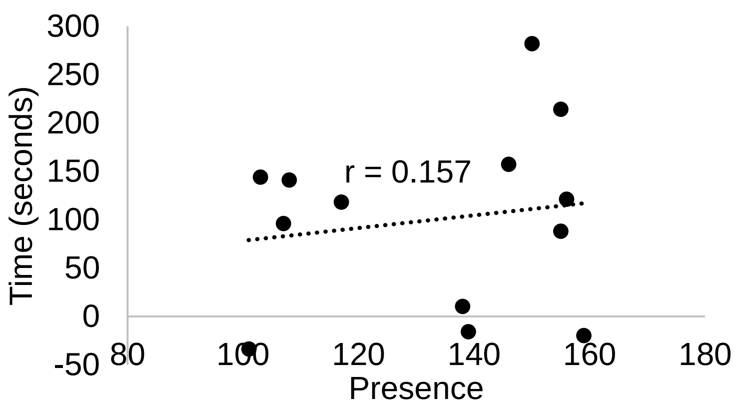


Figure 3.6. correlation between feeling of presence in VR and change in performance between TTE in VR and CON. Dashed line represents line of best fit.

Chapter 4

Discussion

4.1 General Discussion

To the authors knowledge this is the first study to investigate the physiological and perceptual responses to exercise within a fully-immersive virtual environment, and their subsequent impact on performance. The key findings were that exercising whilst using a VR headset resulted in a moderate increase in time to exhaustion, which was likely the result of a large increase in positive affect and a moderate increase in the enjoyment of the exercise.

Similar to prior research that has examined the addition of auditory and/or visual stimuli during exercise, the present study shows that participants achieve a higher level of performance when completing the exercise task in a virtual environment. Analysis of time to exhaustion data showed that performance was improved by ~ 20%. Whilst no direct comparisons can be made to other studies that have used VR during time to exhaustion testing, these results are in agreement with the findings of both Hoffman et al (2014) and Murray et al., (2016), who both showed time trial performance to be improved when combined with desktop virtual reality.

When comparing the results of the current study to previous research that has examined the use of music and video, one potentially interesting finding is that performance was still enhanced even though the exercise task required the participants to cycle at a high intensity. It is reported that the intensity of exercise determines the extent to which auditory and visual stimuli can inhibit the processing of other sensory cues (Karageorghis & Priest, 2012). As such, it has been suggested that the addition of sensory stimuli is most efficacious during low and moderate work intensities. This is due to the physiological cues at high intensities (~170bpm) being too strong for the exerciser to ignore, thereby restoring their perceived exertion to levels observed in a control condition (Boucher & Trenske, 1990, Karageorghis & Priest, 2012). At minute 2 in both conditions the subjects were still working at what could be classified as a moderate intensity (~160bpm). At this time point, despite having a similar HR in both conditions subjects reported a moderately lower RPE in the VR trial. As the exercise continued and the intensity increased to what could be considered high intensity (~170bpm), RPE remained similar in both conditions, even at exhaustion where subjects in the VR condition had been cycling for a longer period of time. What this suggests is that similar to music and video, at lower intensities fully-immersive VR may distract the exerciser from the sensory cues associated with low intensity exercise. However, what these findings also indicate is that although fully immersive VR may not distract exercisers from the fatigue induced by high-intensity exercise, it may alter their perception to that of a more positive evaluation, therefore allowing them to continue exercising (Karageorghis et al., 2009).

The enhanced feelings of positivity are reflected in the psychological questionnaires taken after the completion of the exercise. When examining the changes in affect from pre to post exercise, positive affect in the VR condition was increased by more than double that seen in the control condition. Further to this, the VR condition also saw a 70% increase in the enjoyment of the exercise. These increases in enjoyment and positive affect are in agreement with previous VR research that has shown enjoyment, motivation and positivity to be enhanced (Legrand et al., 2011; Russell & Newton, 2008; Murray et al., 2016). However, similar to the RPE ratings, this difference is noteworthy as it was found in the context of exercise at high intensity and a greater work output. A potential explanation for the heightened increase in positive feelings may be a result of the extra sensory stimulation that fully-immersive VR provides compared to that of music, video, and desktop VR. The extra stimulation provided by the fully-immersive VR may better compete with the sensory feedback and provide a greater distraction to the discomfort experienced with high-intensity exercise. However, there may be another explanation for this dramatic increase in positivity and enjoyment. The correlation between perceived presence in the virtual environment and changes in performance revealed only a *very weak* positive correlation. This suggests that the dissociative feelings brought about by the VR may not have been as key to improving performance as first appears. It is worth noting that none of the participants had used a fully-immersive VR headset other than in the familiarisation session. As fully-immersive VR is a relatively new concept, it would be expected that there was a large novelty factor involved. As such, future investigations may wish to examine the long term usage of this type of equipment to examine the impact that the novelty may have had.

In terms of an explanation as to why the increased enjoyment and positive affect may have influenced performance, these results are perhaps best explained using the psychobiological model developed by Marcora, Staiano and Manning (2009). This model suggests that when the effort required by a task exceeds the amount of effort an individual is willing to exert, or when the effort given is already deemed maximal exercise will be terminated. The increased performance in the VR condition would indicate that participants were willing to exert a greater effort despite similar physiological strain (HR, VO_2, bLac) and perceived exertion. Therefore, the increased feelings of enjoyment and positive affect in the presence of VR may have resulted in greater motivation to continue exercising and exert more effort. In comparison, without the additional stimuli, exercise in the control condition may have been unpleasant and therefore as a result, task disengagement occurred much earlier.

4.2 Limitations, Future Research, and Practical Applications

Aside from the novelty issue mentioned above, It is also worth highlighting that this research was performed using recreationally active participants. Previous studies that have investigated the use of additional sensory stimuli on trained and an untrained participants have suggested that those who are untrained are far more receptive to this form of training aid (Brownley, McMurray, & Hackney, 1995; Mohammadzadeh, Tartibiyan & Ahmadi, 2008). The reason for this being that the focus of trained exercisers (or athletes) rests on the tasks and specifics of their training, whereas the untrained may depend to a greater extent on the positive feelings brought about by visual or auditory stimuli. However, whilst the stimulative properties of the virtual environment used in this study were considerably low (so as to ensure that it was the virtual environment that was enhancing performance rather than anything specific within the environment), there is great scope to create far more stimulative environments that may far better replicate the experiences athletes may feel when competing. This includes the addition of competitors or cognitive tasks for example.

Whilst this study only examined the use of VR during high intensity activity, there may, as with music and video, be a range of benefits to be gained when used at low or moderate intensities. For example, the high levels of enjoyment reported in this study, even at high intensities suggest VR may be of use to those who are only recreationally active. If exercise can be made more enjoyable through the use of VR this may spark an interest for those who wouldn’t normally exercise as well as potentially increasing adherence to exercise programmes.

4.3 Conclusion

Although the addition of fully-immersive virtual reality appears to induce minimal, if any physiological changes, it appears that the psychological and perceptual responses to exercise at high intensity can be considerably improved. As such, the use of this technology would appear to be an appealing option for those looking to induce a greater training stimulus or simply make there exercise more enjoyable. As this form of technology continues to develop at a rapid pace, the experiences and environments available to the exerciser will only continue to improve. As such, future research should continue to investigate the use of this new and upcoming technology and look to expand on the small body of research that currently exists.

Chapter 5

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Chapter 6

Appendices

Appendix A. Participant information sheet

Participant information sheet

The Physiological and Psychological Responses to Cycling Exercise in a Fully Immersive Virtual Reality Environment

You are being invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

What is the purpose of the study?

Virtual reality is an exciting piece of technology that is advancing at a rapid rate. It has already been used in a number of different settings such as gaming, movies, and also as a tool for education.. However, it is possible that virtual reality may also affect the way in which we exercise. The purpose of this study is to determine whether people respond differently to exercise when performed in virtual reality. The study comes from both a health and a performance perspective, potentially offering advances in both areas.

Why have I been chosen?

You have been chosen because you are a healthy, recreationally active adult between the ages of 18-44 who is capable of carrying out the exercise protocols within this study.

Do I have to take part?

It is up to you to decide whether or not to take part. If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect you or your relationship with the researcher in any way.

What will happen to me if I take part?

Before any testing takes place you will be asked to sign a participant consent form and given the opportunity to ask any questions you would like answered relating to the study. You are then required to fill in a health questionnaire and will have several measurements taken including, resting heart rate, blood pressure, height and weight. This is done to ensure it is safe for you to be involved with the study. Upon completion of these measurements, you will perform a VO2max test on a cycle ergometer. This test will require you to continue cycling for as long as you possibly can, with the resistance on the ergometer increasing at a rate of 1W every 3 seconds. You will have your heart rate and perceived exertion measured throughout as well as wearing a facemask that will analyse your oxygen consumption as you exercise. You will also be required to give a blood lactate sample at the end of the test. This process simply involves a small prick to your finger tip.

For your remaining 4 visits you will perform the same exercise each time, however you will experience difference manipulations in relation to the virtual environment. The exercise protocol will again require you to exercise until exhaustion. Instead of the resistance on the bike increasing, this time it will be set at a constant resistance equivalent to the resistance on the bike when you were at 80% of your VO2max during your initial testing. During one of the trials you will complete this test without the addition of any virtual reality. During another trail you will complete the same exercise whilst wearing the virtual reality headset however nothing will be playing throughout. For the remaining two trails you will be cycling in two different virtual environments.

The virtual reality headset itself is much like that of a skiing mask in terms of appearance. The headset allows the wearer to see three dimensional images which give an illusion of depth of perception. It will present you as the wearer with a world that appears realistic and behaves in a similar way to the real world. For example, each time that you move your head, the scene displayed in the mask will change in a similar way to how your view would change in real life if you were looking around.

Each test should take approximately 30 minutes. In total you will be asked to give up approximately 2 hours of your time across 4 separate days of testing for this study.

What are the possible disadvantages and risks of taking part?

Testing requires you to perform maximally during both the VO2max test and the test to exhaustion protocol. The potential side effects related to this form of exercise include: nausea, feeling faint, dizziness, breathlessness, muscle soreness and cardiac arrest. Every effort will be taken both throughout and after the testing period to ensure you remain safe. I have 4 years' experience with this type of testing and will be able to assist should you experience any negative side effects. There will also be a laboratory technician present at all times who is first aid trained.

The potential side effects that may occur as a result of using the virtual reality headset include: Headache, eye strain, difficulty focusing, sweating, blurred vision, dizziness, vertigo, stomach upset and nausea.

Following the guidelines set out in the virtual reality headset user manual the device will be calibrated accordingly. Additionally, the room will also be well ventilated. This will hopefully reduce the chances of you experiencing any of the negative side effects listed above. You will also be reminded that if at any point you are feeling unwell or want to terminate the exercise you must do so. If you do feel unwell, once again, myself and the lab technician will assist you.

After each visit to the laboratory you may experience some fatigue, however this should be no more than you experience with your usual training or exercise and have no long lasting negative effects.

What are the possible benefits of taking part?

You will be given the results of your VO2max test which will give you an accurate up to date account of your current fitness level. These figures can be of particular benefit when setting training zones to inform training programmes. The study will also allow you gain an insight into the world of sports science testing and provide you with some experience of laboratories that may inform your own interests or studies. In addition, you will be able to gain an insight into the application of virtual reality in the exercise setting which is not yet available commercially.

What if something goes wrong?

If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Executive Dean of the Faculty of Science and Engineering, University of Chester, Thornton Science Park, Pool Lane, Ince, Chester CH2 4NU 01244 513197

Will my taking part in the study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential so that only the researcher carrying out the research will have access to such information.

What will happen to the results of the research study?

The results will be written up into a dissertation for my final project of my MSc. Individuals who participate will not be identified in any subsequent report or publication.

Who is organising the research?

The research is conducted as part of a MSc in Sports Physiology within the Department of Sport and Exercise Sciences at the University of Chester. The study is organised with supervision from the department, by myself, Thomas williams, an MSc student and also by fellow MSc student Gerard Nowlan.

Who may I contact for further information?

If you would like more information about the research before you decide whether or not you would be willing to take part, please contact:

Thomas Williams: 1215465@chester.ac.uk or Gerard Nowlan 1218482@chester.ac.uk

Thank you for your interest in this research.

Appendix B. Informed Consent

Title of Project: The Physiological and Psychological Responses to Cycling Exercise in a Fully Immersive Virtual Reality Environment.

Name of Researcher: Thomas Williams

Please initial box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without my legal rights being affected. ☐

3. I agree to take part in the above study. ☐

____________________	____________________	____________________
Name of Participant	Date	Signature
____________________	____________________	____________________
Researcher	Date	Signature

Appendix C. Ethical approval

Faculty of Science and Engineering
Research Ethics Committee

Thomas Benjamin Williams
25 Fairview Drive,
Bayston Hill,
Shrewsbury,
Shropshire,
SY3 0LD

6th April 2016

Dear Thomas,

Study title: The Physiological and Psychological Responses to Cycling Exercise in a fully Immersive Virtual Reality Environment
FSE-REC reference: 038/16/TW/SES
Version number: 2

Thank you for sending your application to the Faculty of Science and Engineering Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Enclosed?	Appendix №	Version №	Date
FSE-REC application form	**Mandatory**	1	2	01/02/16
List of references	**Mandatory**	12	2	01/02/16
Brief C.V. for main researcher	**Mandatory**	3	2	01/02/16
Letter(s) of invitation to participants	**N/A**			
Participant Information Sheet(s) [PIS]	**Y**	5	2	01/02/16
Participant consent form(s)	**Y**	6	2	01/02/16
Information sheets / letters to people	**N/A**			
Written permission from	**N/A**			

relevant personnel (eg. to use facilities) if required				
Interview schedule(s) or topic guide(s) if required	**N/A**			
Questionnaire(s) for the study	**Y**	8,9,10,11	2	
Copies of advertisement material(s) if required	**N/A**			
Risk Assessment form(s)	**Y**	2	2	01/02/16
Other documents *(Please specify below, as necessary)*				
CV for other person involved in study	**Y**	4	2	01/02/16
Participant health questionnaire	**Y**	7	2	01/02/16

In the PIS, under the section 'What will happen to the results of the research study'... please include the following statement which is a recently issued update:

"Participants should note that data collected from this project may be retained and published in an anonymised form. By agreeing to participate in this project, you are consenting to the retention and publication of data."

Please note that this approval is given in accordance with the requirements of English law only. For research taking place wholly or partly within other jurisdictions (including Wales, Scotland and Northern Ireland), you should seek further advice from the Committee Chair / Secretary or the Research and Knowledge Transfer Office and may need additional approval from the appropriate agencies in the country (or countries) in which the research will take place.

With the Committee's best wishes for the success of this project.

Yours sincerely,

Helen Southall
Chair, Faculty of Science and Engineering Research Ethics Committee

Enclosures: Standard conditions of approval.

Cc. Supervisor/FSE-REC Representative

Appendix D. Pre-test health questionnaire

DEPARTMENT OF SPORT AND EXERCISE SCIENCES

UNIVERSITY OF CHESTER

PRE-TEST HEALTH QUESTIONNAIRE

(Please note that this information will be confidential)

Name………………………………………………… DOB…………………………….

Resting blood pressure (mmHg) ………. /……… Resting heart rate (b.min^{-1}) ……………

Stature……………………………………………… Body Mass………………………………

Project Title:

Please answer these questions truthfully and completely. The purpose of this questionnaire is to ensure that you are fit and healthy enough to participate in this laboratory practical/research project.

	Yes	No
1. Have you in the past suffered from a serious illness or accident.	☐	☐

If Yes, please provide details.

…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………...

	Yes	No
2. Have you consulted your doctor the last 6 months	☐	☐

If Yes, please provide details

…………………………………………………………………………………………………
……………………………………………………………………………

3. Do you suffer, or have you suffered from:

	Yes	**No**
Asthma	☐	☐
Diabetes	☐	☐
Bronchitis	☐	☐
Epilepsy	☐	☐
High blood pressure	☐	☐

	Yes	**No**
4. Is there any history of heart disease in your family	☐	☐

	Yes	**No**
5. Are you suffering from any infectious skin diseases, sores, wounds, or blood infections i.e., Hepatitis B, HIV, etc.?	☐	☐

If Yes, please provide brief details.

……………………………………………………………………………………………………
……………………………………………………………………………………………………
………………

	Yes	**No**
6. Are you currently taking any medication	☐	☐

If Yes, please provide details.

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
………………………

	Yes	**No**
7. As far as you are aware, are you pregnant?	☐	☐

	Yes	**No**
8. Are you suffering from a disease that inhibits the sweating process	☐	☐

Yes **No**

9. Is there anything to your knowledge that may prevent you from participating in the testing that has been outlined to you? ☐ ☐

If Yes, please provide details.

……

Your Recent Condition

Yes No

- Have you eaten in the last 2 hours? ☐ ☐

  If Yes, please provide details

  ……

- Evaluate your diet over the last two days. **Poor** **Average** **Good** **Excellent**

Yes **No**

- Have you consumed alcohol in the last 24hr ☐ ☐

Yes **No**

- Have you had any kind of illness or infection in the last 2 weeks ☐ ☐

Yes **No**

- Have you exercised in the last 2 days? ☐ ☐

  If Yes, please describe below

……

Persons will not be permitted to take part in any experimental testing if they:-

- have a known history of medical disorders (i.e. hypertension, heart or lung disease)
- have a fever, suffer from fainting or dizzy spells
- are currently unable to train because of a joint or muscle injury

- have had any thermoregulatory disorder
- have gastrointestinal disorder
- have a history of infectious diseases (i.e. HIV or Hepatitis B)
- have, if pertinent to the study, a known history of rectal bleeding, anal fissures, haemorrhoids or any other similar rectal disorder.

My responses to the above questions are true to the best of my knowledge and I am assured that they will be held in the strictest confidence.

Name: (Participant)………………………………………… Date:………………….

Signed (Participant): ………………………………………

Name: (Lecturer/technician)………………………………. Date:………………….

Signed (Lecturer/technician): ………………………………

Appendix E. I-PANAS-SF Questionnaire

The International Positive and Negative Affect Schedule Short Form (I-PANAS-SF) Question, Measure, and Item Order

1.Upset	❐1	❐2	❐3	❐4	❐5
2. Hostile	❐1	❐2	❐3	❐4	❐5
3. Alert	❐1	❐2	❐3	❐4	❐5
4. Ashamed	❐1	❐2	❐3	❐4	❐5
5. Inspired	❐1	❐2	❐3	❐4	❐5
6. Nervous	❐1	❐2	❐3	❐4	❐5
7. Determined	❐1	❐2	❐3	❐4	❐5
8. Attentive	❐1	❐2	❐3	❐4	❐5
9. Active	❐1	❐2	❐3	❐4	❐5
10. Afraid	❐1	❐2	❐3	❐4	❐5

To what extend do you feel…

Interval measure: *1. strongly disagree 2. Disagree 3. neither agree or disagree 4. Agree 5. Strongly agree*

The International Positive and Negative Affect Scale (short form) (I-PANAS-SF) questionnaire (Thompson, 2007) will be completed by the participants both prior to and upon completion of the TTE test. This questionnaire will be used to assess whether TTE testing under the different treatment conditions has an impact on the participant's affective state. This questionnaire is a refined version of the original PANAS Questionnaire developed by Watson et al., in 1988. It has been significantly shortened and is therefore more suitable for studies in which participants are under time constraints or required to complete numerous questionnaires. Participants are given ten different affective states and required to indicate to what extent they feel the different positive and negative emotions. Ratings range from 1-5, whereby 1 = strongly disagree and 5 = strongly agree. Scores from each emotion are summated to determine an overall score for both positive and negative affect.

Appendix F. PACES Questionnaire

1. I enjoy it	❒1	❒2	❒3	❒4	❒5
2. I feel bored	❒1	❒2	❒3	❒4	❒5
3. I dislike it	❒1	❒2	❒3	❒4	❒5
4. I find it pleasurable	❒1	❒2	❒3	❒4	❒5
5. It's no fun at all	❒1	❒2	❒3	❒4	❒5
6. It gives me energy	❒1	❒2	❒3	❒4	❒5
7. It makes me depressed	❒1	❒2	❒3	❒4	❒5
8. It's very pleasant	❒1	❒2	❒3	❒4	❒5
9. My body feels good	❒1	❒2	❒3	❒4	❒5
10. I get something out of it	❒1	❒2	❒3	❒4	❒5
11. It's very exciting	❒1	❒2	❒3	❒4	❒5
12. It frustrates me	❒1	❒2	❒3	❒4	❒5
13. It's not at all interesting	❒1	❒2	❒3	❒4	❒5
14. It gives me a strong feeling of success	❒1	❒2	❒3	❒4	❒5
15. It feels good	❒1	❒2	❒3	❒4	❒5
16. I feel as though I would rather be doing something else	❒1	❒2	❒3	❒4	❒5

When I am active… (1) Disagree a lot … (5) Agree a lot

This questionnaire was originally designed by Kendzierski and DeCarlo (1991) however, a shortened, more simplified version has been developed by Motl et al., (2001). The version by Motl et al., (2001) has been chosen as more appropriate for use within this study due to the large number of questionnaires participants are required to complete throughout the study. This questionnaire requires participants to rate 16 questions on a 5 point Likert scale whereby 1 = strongly disagree and 5 = strongly agree. Positive statement scores such as "I enjoy it" are calculated at face value. The values of negative statement scores such as "it frustrates me" are reverse scored. Statement scores are then summated to rate the level of enjoyment. This form of questionnaire has been used previously in studies examining exercise in virtual reality (Murray et al.,2015; Plante, Cage, Clements & Stover, 2006) and is the most widely used form of questionnaire for self-reported enjoyment of exercise (Mullen et al., 2011).

Appendix G. Simulator sickness questionnaire

Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal,1993). The SSQ is made up of 16 different symptoms (e.g. eye strain, dizziness). Participants are required to indicate to what extent they experienced each symptom on a 4 point Likert scale where 0 = none and 3 = severe. These 16 items form three subscales: Nausea, Oculomotor disturbances, and Disorientation. The three subscales are computed by adding the scores for the components of each subscale together, and then multiplying them by the appropriate weighting factor (Nausea – 9.54, Oculomotor disturbances – 7.58, Disorientation – 13.92). Total score for SSQ is then the sum of these three subscales multiplied by 3.7. This questionnaire is currently the most popular way of which to measure simulator sickness (Balk, Bertola, & Inman, 2013) and as of January 2016 has been cited in over 1400 studies (Google Scholar, 2016).

Instructions: Circle how much each symptom below is affecting you right now

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe

8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. Fullness of the Head	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. Vertigo	None	Slight	Moderate	Severe
15. Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

Categories

Nausea – general discomfort, increased salivation, sweating, nausea, difficulty concentrating, stomach awareness, burping

Oculomotor – general discomfort, fatigue, headache, eye strain, diffculty focusing, difficulty concentrating, blurred vision

Disorientation – difficulty focusing, nausea, head fullness, blurred vision, dizzy eyes open, dizzy eyes closed, vertigo

Appendix H. Presence Questionnaire

(Witmer & Singer, 1998). The PQ is used to measure the degree to which an individual experiences presence in a virtual environment. It is also used to assess what factors within that virtual world either increased or decreased this feeling. The PQ uses 32 questions based upon the two main aspects of presence, these being involvement and immersion. The PQ uses a 7 point scale format based on the semantic differential principle (Dyer et al., 1976). Each end item is anchored at the end by opposing descriptors. However, unlike the semantic differential it also includes a midpoint anchor. The anchors are based upon the content of the question. Participants are required to place an 'X' in the appropriate box in accordance with the content of the question and the descriptive labels. The scale ranges from 1-7, with the score of each answer summated to give an overall rating of presence.

Characterize your experience in the environment, by marking an "X" in the appropriate box of the 7-point scale, in accordance with the question content and descriptive labels. Please consider the entire scale when making your responses, as the intermediate levels may apply. Answer the questions independently in the order that they appear. Do not skip questions or return to a previous question to change your answer.

WITH REGARD TO THE EXPERIENCED ENVIRONMENT….

1. How much were you able to control events?

NOT AT ALL **SOMEWHAT** **COMPLETELY**

2. How responsive was the environment to actions that you initiated (or performed)?

NOT RESPONSIVE **MODERATELY RESPONSIVE** **COMPLETELY RESPONSIVE**

3. How natural did your interactions with the environment seem?

EXTREMELY ARTIFICAL **BORDERLINE** **COMPLETELY NATURAL**

4. How much did the visual aspects of the environment involve you?

NOT AT ALL **SOMEWHAT** **COMPLETELY**

5. How much did the auditory aspects of the environment involve you?

NOT AT ALL **SOMEWHAT** **COMPLETELY**

6. How natural was the mechanism which controlled movement through the environment?

EXTREMELY ARTIFICAL **BORDERLINE** **COMPLETELY NATURAL**

7. How compelling was your sense of objects moving through space?

NOT AT ALL **MODERATELY COMPELLING** **VERY COMPELLING**

8. How much did your experiences in the virtual environment seem consistent with your real world experiences?

NOT CONSISTENT **MODERATELY CONSISTENT** **VERY CONSISTENT**

9. Were you able to anticipate what would happen next in response to the actions that you performed?

NOT AT ALL **SOMEWHAT** **COMPLETELY**

10. How completely were you able to actively survey or search the environment using vision?

NOT AT ALL | SOMEWHAT | COMPLETELY

11. How well could you identify sounds?

NOT AT ALL | SOMEWHAT | COMPLETELY

12. How well could you localize sounds?

NOT AT ALL | SOMEWHAT | COMPLETELY

13. How well could you actively survey or search the virtual environment using touch?

NOT AT ALL | SOMEWHAT | COMPLETELY

14. How compelling was your sense of moving around inside the virtual environment?

NOT COMPELLING | MODERATLEY COMPELLING | VERY COMPELLING

15. How closely were you able to examine objects?

NOT AT ALL | PRETTY CLOSELY | VERY CLOSELY

16. How well could you examine objects from multiple viewpoints?

NOT AT ALL | SOMEWHAT | EXTENSIVELY

17. How well could you move or manipulate objects in the virtual environment?

NOT AT ALL **SOMEWHAT** **EXTENSIVELY**

18. How involved were you in the virtual environment experience?

NOT INVOLVED **MILDLY INVOLVED** **COMPLETELY ENGROSSED**

19. How much delay did you experience between your actions and expected outcomes?

NO DELAYS **MODERATE DELAYS** **LONG DELAYS**

20. How quickly did you adjust to the virtual environment experience?

NOT AT ALL **SLOWLY** **LESS THAN ONE MINUTE**

21. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

NOT PROFICIENT **REASONABLY PROFICIENT** **VERY PROFICIENT**

22. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

NOT AT ALL **INTERFERED SOMEWHAT** **PREVENTED TASK PERFORMANCE**

23. How much did the control devices interfere with the performance of assigned tasks or with other activities?

NOT AT ALL **INTERFERED SOMEWHAT** **INTERFERED GREATLY**

24. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

NOT AT ALL **SOMEWHAT** **COMPLETELY**

25. How completely were your senses engaged in this experience?

NOT ENGAGED **MILDLY ENGAGED** **COMPLETELY ENGAGED**

26. To what extent did events occurring outside the virtual environment distract from your experience in the virtual environment?

NOT AT ALL **MODERATELY** **VERY MUCH**

27. Overall, how much did you focus on using the display and control devices instead of the virtual experience and experimental tasks?

NOT AT ALL **SOMEWHAT** **VERY MUCH**

28. Were you involved in the experimental task to the extent that you lost track of time?

NOT AT ALL **SOMEWHAT** **COMPLETELY**

29. How easy was it to identify objects through physical interaction; like touching an object, walking over a surface, or bumping into a wall or object?

IMPOSSIBLE **MODERATELY DIFFICULT** **VERY EASY**

30. Were there moments during the virtual environment experience when you felt completely focused on the task or environment?

NONE **OCCASSIONALY** **FREQUENTLY**

31. How easily did you adjust to the control devices used to interact with the virtual environment?

DIFFICULT **MODERATE** **EASILY**

32. Was the information provided through different senses in the virtual environment (e.g., vision, hearing, touch) consistent?

NOT CONSISTENT **SOMEWHAT CONSISTENT** **VERY CONSISTENT**